# Optical Mining at Mines – Precursory Results

Timofey Broslav[1], Chris Dreyer[1], John Schmit[1], Grant Kahl[1], Sarah Heckel[1], Joel C. Sercel[2]
[1]Center for Space Resources, Colorado School of Mines
[2]TransAstranautica Corporation, 13539 Desmond St., Los Angeles, CA 91331

## Introduction

### Background

- In-Space Resource Utilization (ISRU) drives down costs of space exploration missions, and enables major technological improvement
- Water, Silicates, Organics, and other compounds have been detected on Asteroid bodies [1]
- Optical Mining presents a non-contact method for harvesting asteroid volatiles utilizing the power of the sun [2]
- Optical Mining utilizes thermal spalling to excavate thin portions of an asteroid and heat them to release hydrated content of the minerals.

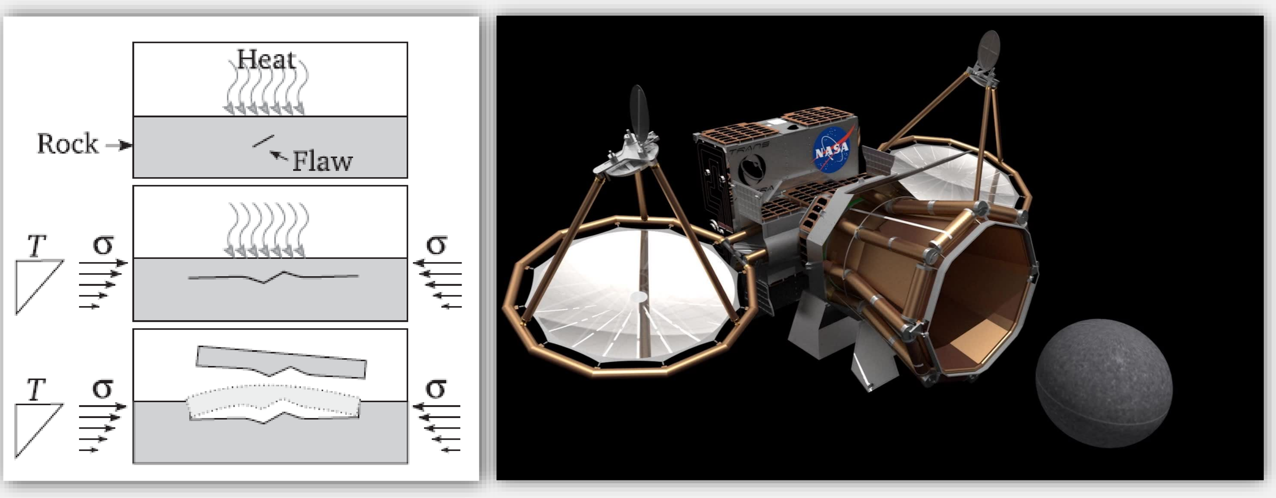



**Figure 1.** Buckling Failure Mechanism for Thermal Spalling (L) Trans-Astra's Optical Mining Concept (R) [2-3]

### Objectives

- Advance understanding of Optically Induced Thermal Spallation and its application to excavation of Asteroids
- Define Spallability criteria of a body w.r.t ISRU capability
- Predict steady-state response of a body undergoing Optical Mining
- Predict Excavation rates of material undergoing Optical Mining
- Optimize parameters of the Optical Mining Process

## Methods

### Experimental Methods

- Experiments used a 15 kW Xenon Arc lamp bulb and a parabolic reflector to focus light unto an asteroid simulant under vacuum conditions in the Apollo Vacuum Chamber (Fig. 2-4)
- Experiments varied from 12 min – 60 min
- Pressure and load cell data was collected to monitor gas release and excavation mass loss from the sample during experiments and track the state of the system
- A Residual Gas Analyzer (RGA) and LN2 Cold Trap were used to study volatile production
- Beam Analysis experiments used a water cooled Gardon Gauge assembly to analyze the irradiance distribution of the light beam
- Property testing of asteroid simulant cores were conducted to obtain thermo-mechanical properties for use as inputs into a spallation prediction model(e.g thermal conductivity, Youngs modulus, compressive strength, Weibull statistical properties, etc)

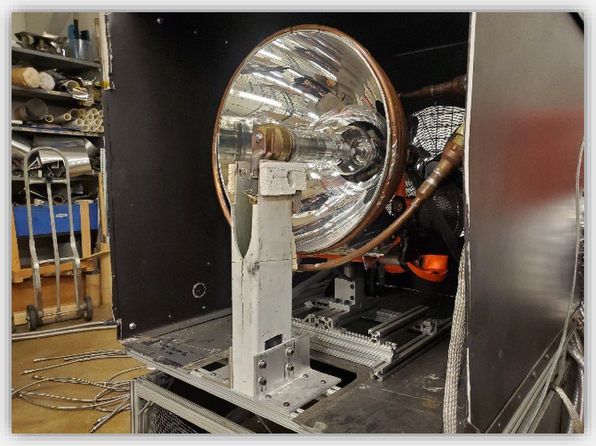


**Figure 2.** Xenon Lamp and Reflector Assembly

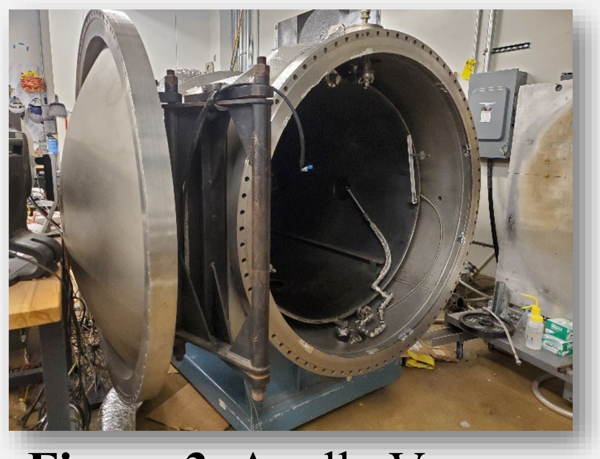


**Figure 3.** Apollo Vacuum Chamber

**Figure 4.** Spalled Nectar Simulant

## Methods (cont.)

### Experimental Methods

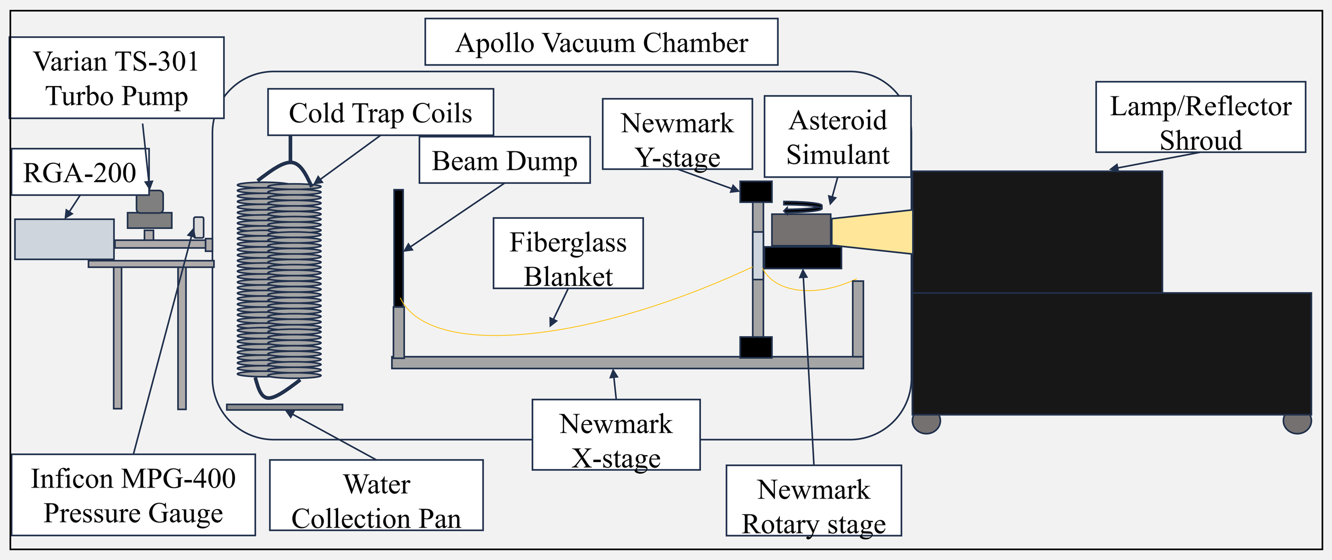



**Figure 5.** Sketch of Optical Mining Experimental System

### Modeling Methods

- 1-D thermal and mechanical model to predict excavation rates,
- Transient thermal conduction with a constant temperature B.C and a radiation B.C modeled using the Explicit Eulers Method (Eq 1.)
- Plane stress conditions were assumed and thermal stresses were estimated using Eq. 2
- Temperature Dependent Properties for rocks (Youngs Modulus, conductivity, etc)
- Weibull probability function for rock failure was used to estimate the stress induced spallation event (Eq. 3) [4]

$$T_1^{k+1} = T_1^k + 2\alpha_{th}\frac{\Delta t}{\Delta x^2}\left(\theta^k\right) + \frac{2Q_I\Delta t}{\rho C_p \Delta x}\left(1-e^{-\beta x_1}\right) - 2\frac{\Delta t}{2}s\varepsilon\left(T_1^k\right)^4 \tag{1}$$

Time Step; Incident Heat Flux; Density; Absorption Coefficient; Radiation Heat loss; Thermal Diffusivity; Spatial Step; Adj. Nodal Temp. Diff.; Heat Capacity; Lin. Therm. Expansion Coeff.

$$\sigma = \frac{E\alpha\theta^k}{1-\nu} \tag{2}$$

Nodal Compressive Stress; Poissons Ratio

$$\Pr = 1 - e^{-\frac{A}{\sigma_0^m}\sum\left(\frac{\sigma_1^m}{2}+\sigma_i^m \ldots + \frac{\sigma_N^m}{2}\right)dx} \tag{3}$$

Probability of Failure; Homogeneity Factor; Inherent Strength

## Results

### Experimental Results

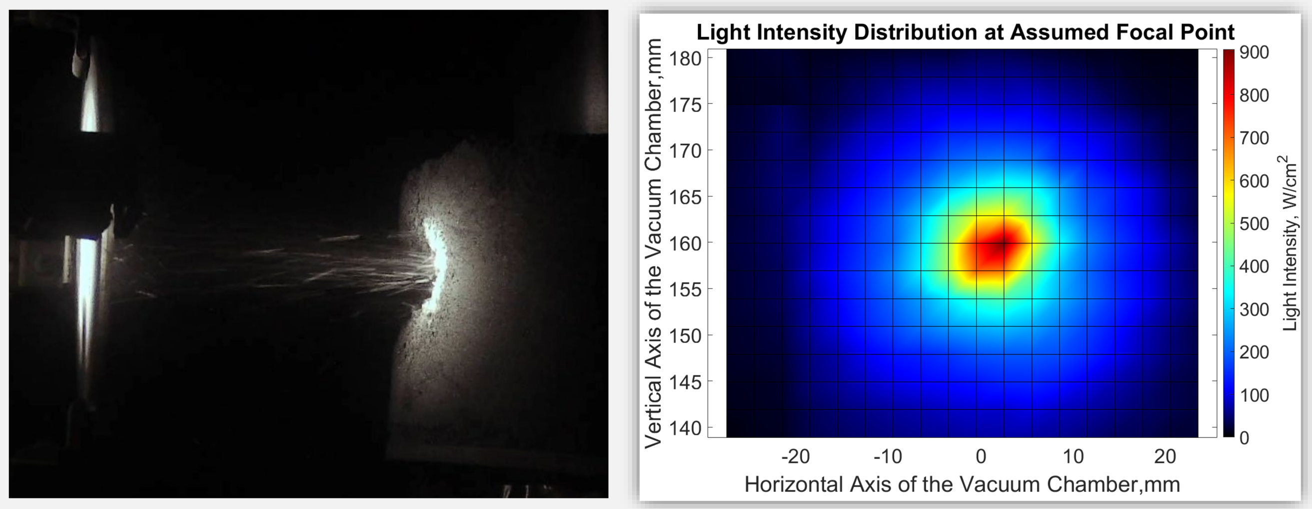
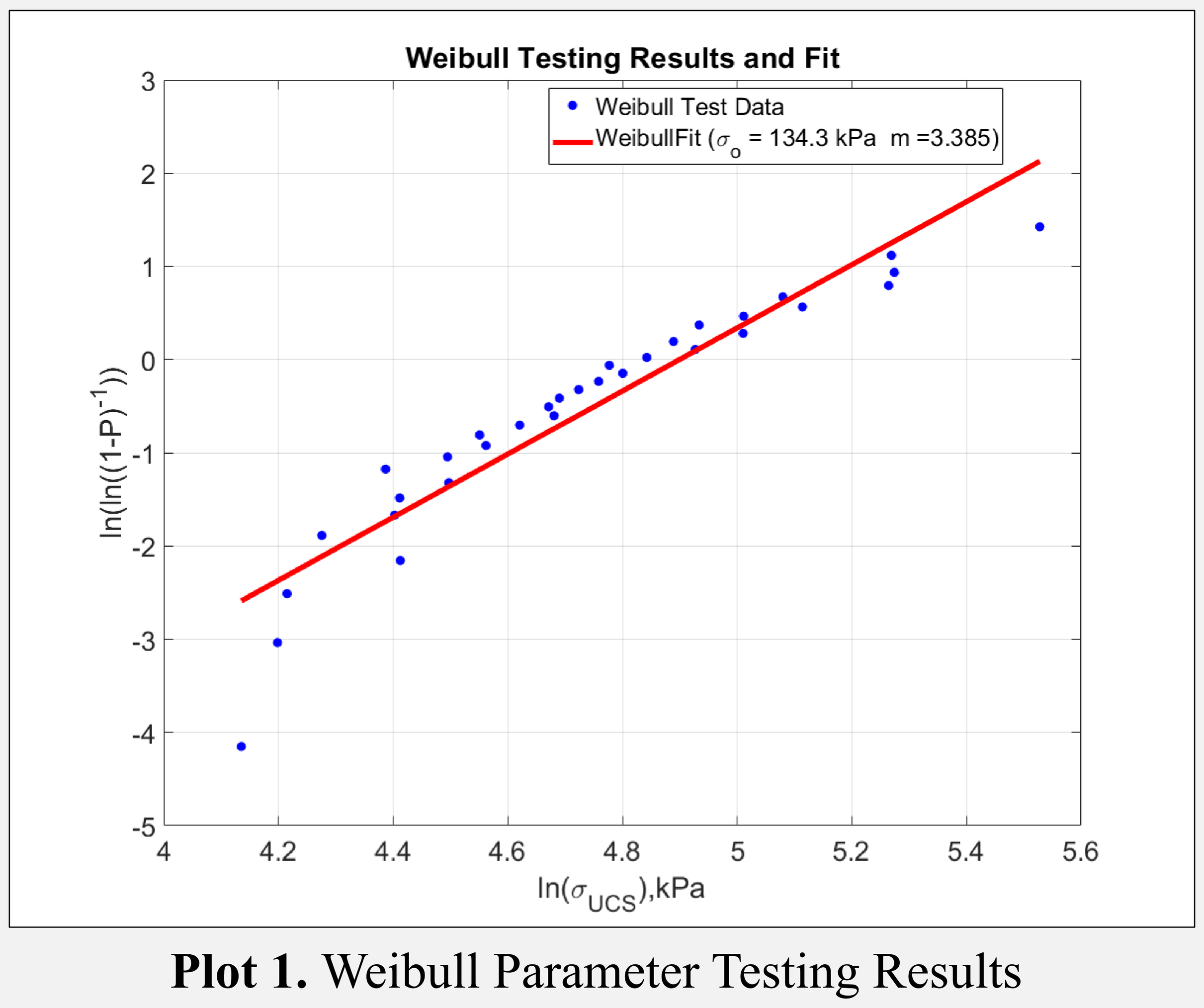



**Figure 6.** Spalling Asteroid Simulant (L) Irradiance of Light Beam at Focus (R)




**Plot 1.** Weibull Parameter Testing Results

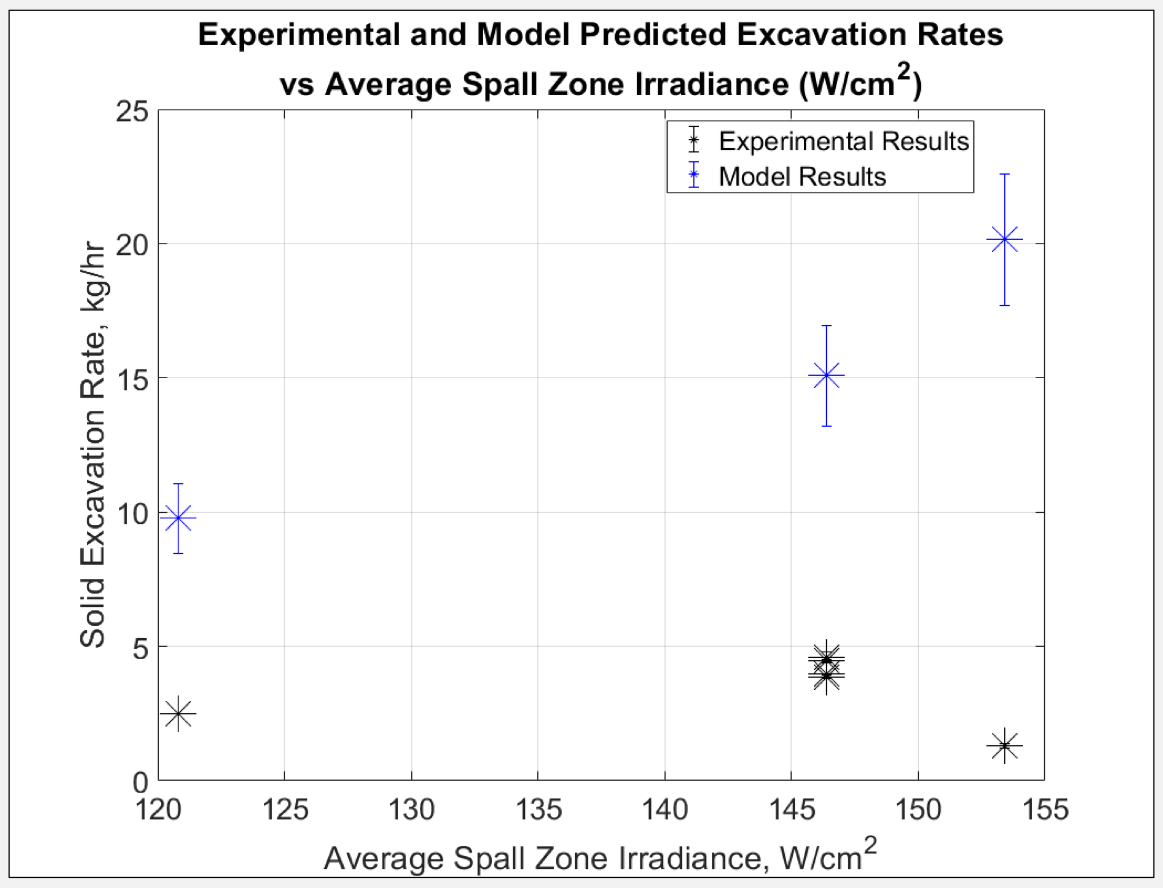
## Results (cont.)

### Experimental Results

**Table 1.** Experimental Results Summary

| Avg. Spall Zone Irradiance | Avg. Excavation Rate (kg/hr) | Avg. Water Collection Rate (g/hr) |
|---|---|---|
| 120.8 | 2.49 | 16 |
| 146.4 | 3.97 | 29 |
| 153.4 | 1.3 | 55 |
| 146.4 | 4.47 | 29 |
| 146.4 | 3.84 | 20 |
| 146.4 | 4.6 | 22 |

### Model Results




**Plot 2.** Model and Experimental Excavation Comparison

## Discussion

- High temperature rise during Spallation has a significant effect on excavation rate
- Water Collected is <5% of the excavated mass
- Excavation can be predicted within a factor of 1
- Estimated excavation rates are highly dependent on Weibull parameters (m and $\sigma_o$)
- Current Weibull Model estimates high spallation times and large spallation thicknesses compared to experimental observations

## Conclusion/Future Work

- Current Model rate predicts excavation rate ~5x higher than observed, this may be due to chemical reactions that are occurring, sintering/melt, or thermo-physical temp. dependent properties
- Incorporate a thermal/mechanical FEA to predict spallation time, spall depth, excavation rates
- Incorporate further melting mechanics and chemical reactions for heat sinks
- Assess water collection measurements
- Volatile efficiency of Optical Mining
- Volatile production model from spall fragments

## References

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3. Walsh, Stuart DC, and Ilya N. Lomov. "Micromechanical modeling of thermal spallation in granitic rock." *International Journal of Heat and Mass Transfer* 65 (2013): 366-373.
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## Acknowledgements

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